

# Evidence for a GW Background at nHz Frequencies

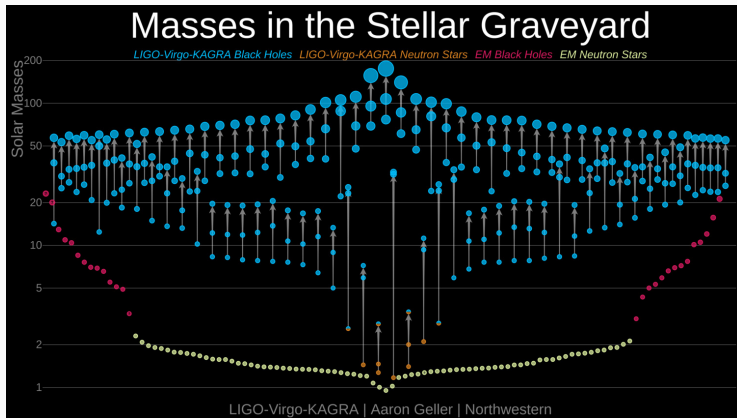
Twelve key messages in twelve minutes

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University of Münster, Institute for Theoretical Physics

TAUP 2023, University of Vienna | August 28, 2024

# 1) Next milestone in GW astronomy: detection of a stochastic GWB

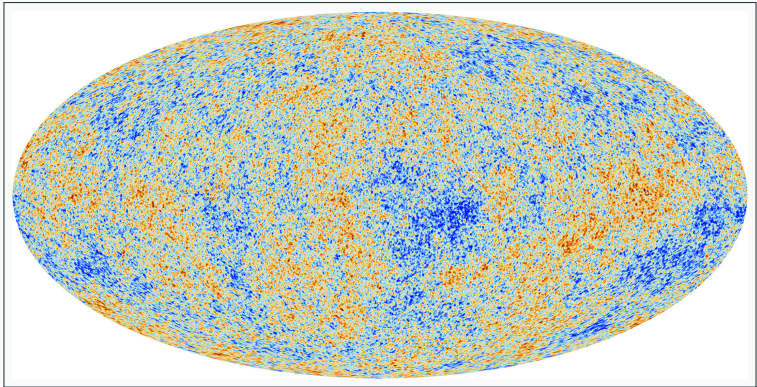


- **Status:** LVK now routinely observe transient GW signals of astrophysical origin
- **Next milestone:** Detection of a stochastic GW background (GWB)
- **Big news on June 29:** **Compelling evidence** for a GWB reported by several teams!

## 2) GWB: 21st-century equivalent of the 20th-century discovery of the CMB

20th century

[PLANCK Collaboration]

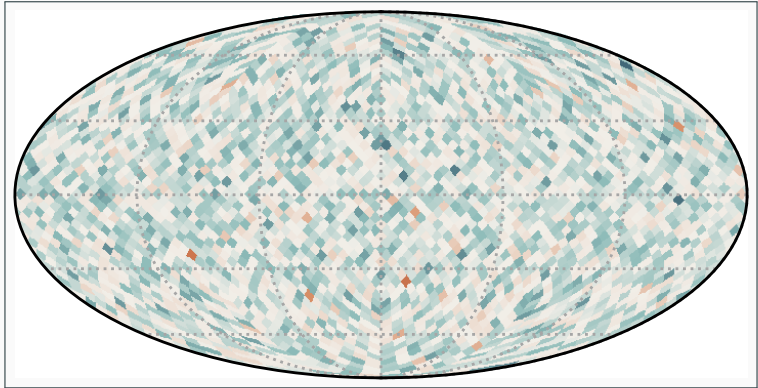


**CMB:** Cosmic microwave background  
**Relic photons** from the early Universe

## 2) GWB: 21st-century equivalent of the 20th-century discovery of the CMB

21th century

[Sato-Polito, Kamionkowski: 2305.05690]



**GWB:** Gravitational-wave background

**Relic gravitational waves from the early Universe  $\sim$  *or*  $\sim$  astrophysical signal**



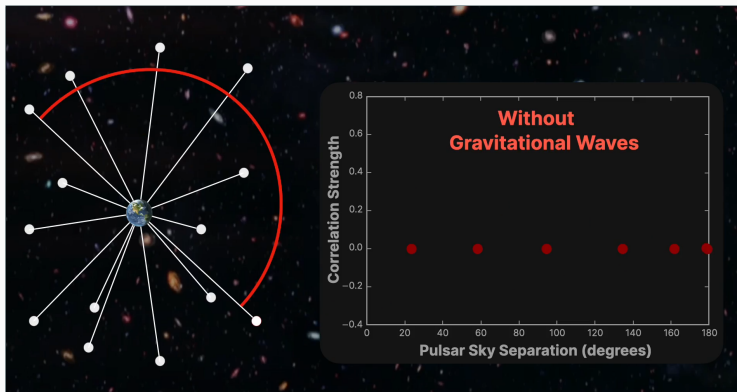
### 3) PTAs are galaxy-sized GW detectors that allow us to search for nHz GWs



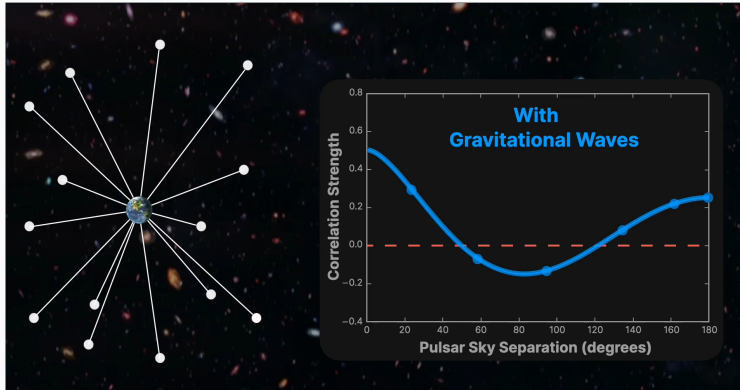
Array of pulsars across the Milky Way → GW detector of galactic dimensions!

- Look for tiny distortions in pulse travel times caused by nanohertz GWs.
- Signal builds up over time; monitor PTA over years and decades.

#### 4) Hallmark signature in cross-correlation of timing residuals of pulsar pairs



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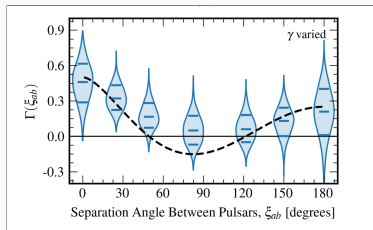


Quadrupolar correlations described by Hellings–Downs (HD) curve

[Hellings, Downs: *Astrophys. J.* 265 (1983) L39]

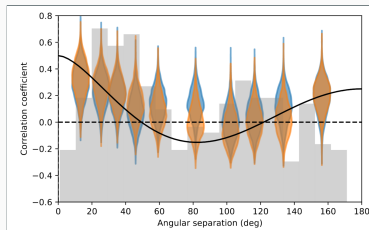
## 5) Major announcement on June 29: compelling evidence for HD correlations

### 2306.16213: NANOGrav



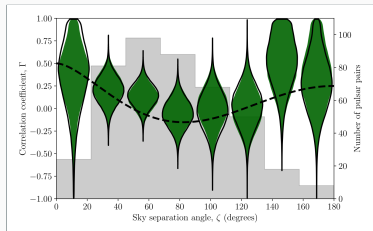
68 pulsars, 16 yr of data, HD at  $\sim 3 \cdots 4 \sigma$

### 2306.16214: EPTA+InPTA



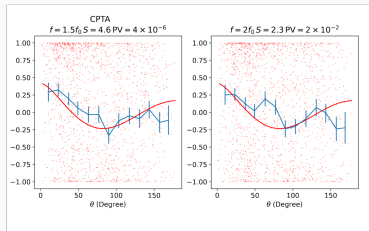
25 pulsars, 25 yr of data, HD at  $\sim 3 \sigma$

### 2306.16215: PPTA



32 pulsars, 18 yr of data, HD at  $\sim 2 \sigma$

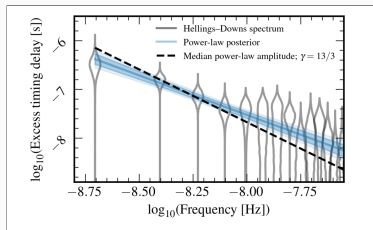
### 2306.16216: CPTA



57 pulsars, 3.5 yr of data, HD at  $\sim 4.6 \sigma$

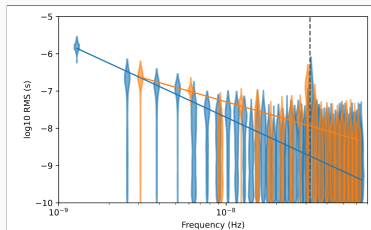
## 6) Spectral characterization: at present, in terms of a simple power-law fit

2306.16213: NANOGrav



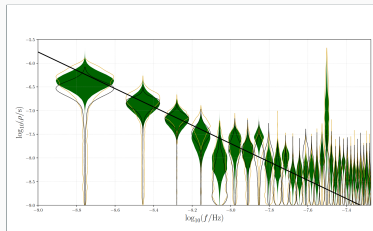
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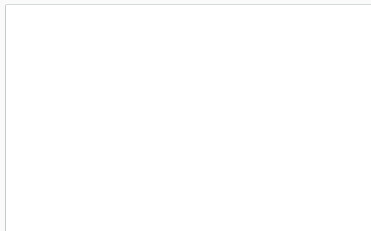
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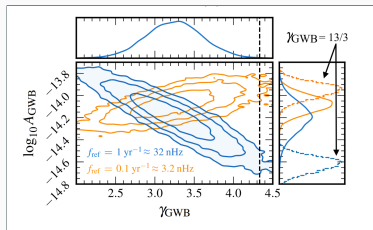
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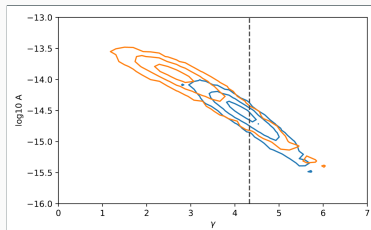
## 7) Results are consistent among the most recent PTA data sets

2306.16213: NANOGrav



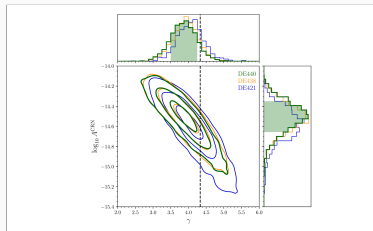
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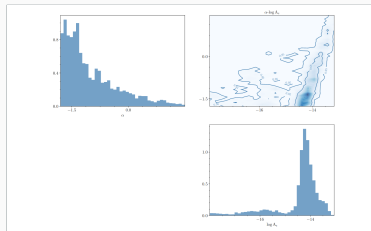
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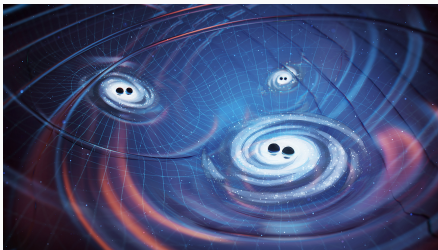
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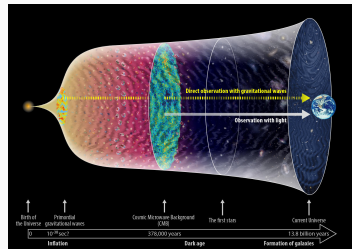
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## 8) Interpretation: SMBHBs (realistic) or new physics (speculative)

### ① Supermassive black-hole binaries



### ② GWs from the Big Bang



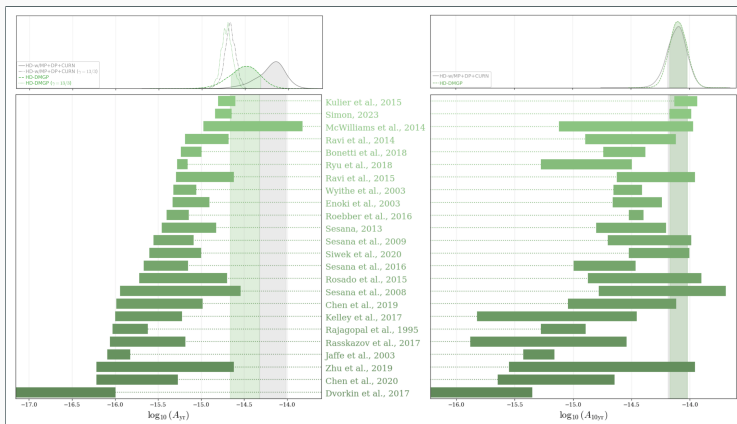
- **SMBHBs:** No SMBHB mergers observed → data-driven field thanks to PTAs
- **New physics:** Probe cosmology at early times, particle physics at high energies

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**BSM scenarios:** Inflationary gravitational waves, scalar-induced gravitational waves, cosmological phase transition, cosmic strings, domain walls, axions, and many more

## 9) SMBHBs: viable explanation, but unexpected corners of parameter space

[NANOGrav 2306.16220]

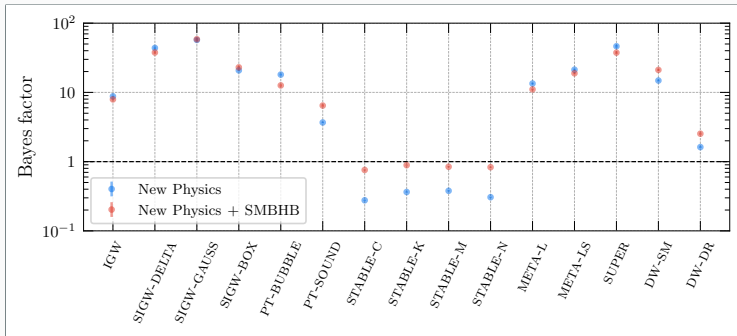


- Parameter shifts towards larger GWB amplitudes than previously expected
- Self-consistent phenomenological description of environmental interactions
- Generally higher binary masses or densities, or highly efficient binary mergers



## 10) New physics: many models can fit the data, but situation inconclusive

[NANOGrav 2306.16219] [See also: EPTA 2306.16227]



### Bayesian model comparison

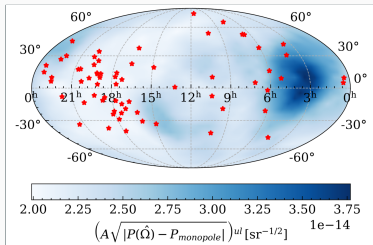
Reference model:  $\mathcal{H}_0 = \{\text{SMBHBs only}\}$

- Many BSM models reach Bayes of order  $10 \cdots 100$ .
- Interesting but not conclusive. Lots of uncertainties in SMBHB and BSM models.
- Bayes factors are sensitive to prior choices. No unique null distribution for  $\mathcal{H}_0$ .

# 11) Complementary observables: anisotropies, continuous-wave signals

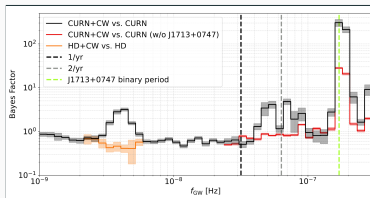
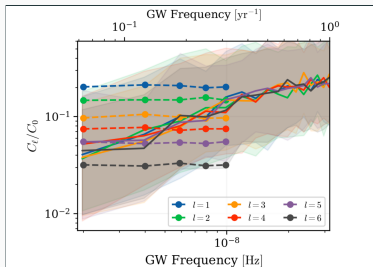
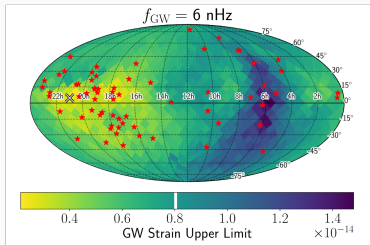
## Anisotropies

[NANOGrav 2306.16221]



## Continuous wave

[NANOGrav 2306.16222]



## 12) Promise: deep insights into galaxy and BH evolution, or BSM physics



- **Status:** Common-spectrum process;  $2 \cdots 4.6 \sigma$  evidence for HD correlations
- **Next:** HD correlations at  $5 \sigma$ , spectral shape, anisotropies across the sky, ...

## Summary: Twelve key messages in twelve minutes

1. Next milestone in GW astronomy: detection of a stochastic GWB
2. GWB: 21st-century equivalent of the 20th-century discovery of the CMB
3. PTAs are galaxy-sized GW detectors that allow us to search for nHz GWs
4. Hallmark signature in cross-correlation of timing residuals of pulsar pairs
5. Major announcement on June 29: compelling evidence for HD correlations
6. Spectral characterization: at present, in terms of a simple power-law fit
7. Results are consistent among the most recent PTA data sets
8. Interpretation: SMBHBs (realistic) or new physics (speculative)
9. SMBHBs: viable explanation, but unexpected corners of parameter space
10. New physics: many models can fit the data, but situation inconclusive
11. Complementary observables: anisotropies, continuous-wave signals
12. Bright future: deep insights into galaxy and BH evolution, or BSM physics

# Stay tuned!

And thanks a lot for your attention